Temporal and EMG Relationships among the Phases of Vertical and Depth Jumps

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Plyometric exercises blend speed and strength training and are often used to help an athlete reach his or her ultimate power potential. Specifically, plyometric training is a technique that enhances neuromuscular excitability, which may in turn increase the ability to achieve a greater work output.

The purpose of this study was to examine the temporal and EMG differences between two different jumping techniques: a vertical jump and depth jumps of varying heights. The study consisted of 20 female physical education majors grouped as skilled or unskilled. Temporal and EMG data were collected for (a) the duration of time spent in each phase, (b) the kinematic similarities and differences for each phase, (c) peak EMG activity between groups for six leg muscles, and (d) the peak EMG among the different jumping conditions for each of the muscles. A split-plot factorial ANOVA was calculated for each of the dependent variables.

Results indicated that skilled jumpers spent more time in the eccentric and concentric phases than unskilled jumpers, but both groups spent approximately equal time in the coupling phase. No differences existed in the eccentric or coupling phase times among the three depth jumps, but differences existed in the concentric phase. Finally, time spent in the coupling and concentric phases measured by the cessation of motion of the center of gravity, hips, knees, and ankles was not the same for the skilled and unskilled groups, but no differences existed for the eccentric phase.
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Coaches and athletes are continually searching for a training method to help enhance an athlete's performance. In many athletic events, improving explosive movement, also known as power, gives an athlete this edge. Plyometric exercises blend speed and strength training and are used to help an athlete reach his or her ultimate power potential.

The goal of plyometric training is to develop efficiency in the stretch-shortening cycle (SSC) of muscle action. There are two factors responsible for the muscle action of the SSC: (1) the serial elastic components of muscles, tendons, and muscle fiber proteins actin and myosin; and (2) the sensors in the muscle spindles ( proprioceptors) that play a role in the activation of the stretch reflex (Chu, 1992). Muscle elasticity is an important factor in understanding how the SSC produces more power than concentric muscle contractions alone. The serial elastic components are capable of briefly storing the elastic energy developed by a rapid stretching phase and reusing it during the concentric phase. During a plyometric exercise, the target muscle group undergoes an eccentric contraction stimulating the proprioceptors sensitive to rapid stretch and loads the serial elastic components with tension from which they rebound during the concentric contraction.

The level of muscular activity present during the eccentric phase determines the amount of elastic energy stored. The greater the tension in the muscle being stretched, the greater the potential to store elastic energy. Therefore, the stretching
phase should be resisted by muscular effort in order to maximize the storage of elastic energy. This process occurs naturally as the body tries to overcome the ground forces upon contact during depth jumps (Conatser, 1995).

In order for the body to maximize the use of the stored elastic energy, the concentric phase of the SSC must occur immediately following the eccentric phase because the stored energy can be lost in the form of heat production. Therefore, it is the goal in plyometrics to shorten the time between the eccentric phase and the concentric phase, which is referred to as the coupling phase of the SSC.

Problem Statement

The problem of the study was to attempt to verify a coupling phase in a jumping movement and to determine the effect of depth jumping on the electromyographic (EMG) responses of leg muscles in female college physical education majors. Specifically, the researchers compared temporal data and the EMG responses of skilled jumpers and unskilled jumpers for the three phases (eccentric, concentric, and coupling) of a depth jump performed at three different heights: 1, 2, and 3 ft, and for the traditional standing vertical jump.

Purpose Statement

The purpose of the study was to compare the temporal data and EMG responses of six leg muscles during the concentric, eccentric, and coupling phases of depth jumps and a vertical jump. There was no direct benefit to the subjects who participated in the study; however, expanding the knowledge about the coupling phase and the recruitment of the muscles during depth jumps could establish better training techniques that utilize the SSC of the muscles when developing muscular
power. A comparison of depth jumps performed at different heights could provide information concerning the optimal height that will result in the greatest storage of elastic energy in the muscles.

The use of plyometrics in athletic training programs has become quite prevalent. Unfortunately, research concerning plyometrics is not as prevalent. It is important that the mechanism or mechanisms inherent in this training technique are better understood.

Delimitations

This study was delimited to the following characteristics:

1. The study was comprised of 20 female Western Michigan University physical education majors not involved in intercollegiate athletics.

2. All subjects were apparently healthy according to ACSM guidelines.

3. The subjects had no history of injuries to the lower extremity in the last 6 months.

4. All subjects performed two different jumping techniques: (1) the vertical jump (VJ), and (2) the plyometric jump (depth jump).

5. The subjects were divided into two groups, skilled and unskilled, based on results of a VJ test.

6. All subjects performed depth jumps from three heights: (1) 1 ft, (2) 2 ft, and (3) 3 ft.

7. All subjects performed three trials for each depth jump and for the VJ.

8. For each jump, the trial in which the subject jumped the highest was chosen for analysis.
9. Six muscles of the lower extremity were analyzed by surface electrode: (1) biceps femoris (BF), (2) rectus femoris (RF), (3) vastus medialis (VM), (4) semimembranosus/semitendinosus (SS), (5) medial head of the gastrocnemius (MG), and (6) peroneal group (PG).

10. Two-dimensional cinematography was used to analyze the phases of the jumps.

Limitations

The research was limited by the following:

1. The study involved only 20 subjects, which could have affected the external validity of the study.

2. The wires attaching subjects to the EMG could have inhibited the subjects' ability to jump, thereby affecting the results.

Assumptions

The basic assumptions of the research were as follows:

1. The subjects were properly warmed up at the time that the trials were performed.

2. The subjects performed to the best of their ability on all trials.

3. The electromyograph, camera, computer, and software were all operating properly.

Hypotheses

This study was conducted to test the following hypotheses:
1. Skilled jumpers had different eccentric, concentric, and coupling phase times than unskilled jumpers.

2. The coupling time was different for the three depth jumps.

3. The eccentric phase time was greater for the 3-ft depth jump than for the 2-ft depth jump, and greater for the 2-ft depth jump than for the 1-ft depth jump.

4. The concentric phase time was the same for the three depth jumps and the VJ.

5. For the six muscles, peak EMG was greater for the 3-ft depth jump than for the 2-ft depth jump, greater for the 2-ft depth jump than for the 1-ft jump, and the same for the 1-ft jump and the vertical jump.

6. For the six muscles, the peak EMG was different for the skilled and unskilled groups.

7. The center of gravity, hip, knee, or ankle methods for determining the coupling phase were different for the 3-ft depth jump, 2-ft depth jump, 1-ft depth jump, and VJ.

8. The center of gravity, hip, knee, or ankle methods for determining the coupling phase were different for the skilled and unskilled groups.

Definition of Terms

The following terms and definitions are applicable and important to the understanding of this study:

1. *Eccentric contraction*: A muscular contraction that occurs when the muscle fibers lengthen under tension (Chu, 1992).

2. *Concentric contraction*: A muscular contraction that occurs when the muscle fibers pull together and shorten (Chu, 1992).
3. **Eccentric phase**: The period of the jump performance that begins when the subject contacts the ground and ends when downward motion ceases.

4. **Concentric phase**: The period of the jump performance from the beginning of upward motion until takeoff.

5. **Coupling phase**: The period of the jump performance from the end of downward motion to the beginning of upward motion.

6. **Stretch-shortening cycle**: Muscular action in which the eccentric phase is followed immediately by the concentric phase.

7. **Stretch reflex**: An involuntary action that occurs when the muscle is stretched rapidly and with large amounts of force. The muscle spindle reacts to the sudden stretch by sending signals to the spinal cord to contract the muscle (Gray, 1991).

8. **Depth jump**: A type of plyometric exercise performed by stepping out from a box and dropping to the ground and then attempting to immediately jump back up to the height of the box.

9. **PG**: Peroneal group—a muscle group referring specifically to the peroneus longus and peroneus brevis.
Plyometric training is a training technique designed to blend speed and strength training to improve muscular power. Chu (1992) defined plyometrics as "exercises that enable a muscle to reach maximum strength in as short a time as possible" (p. 1). Training programs for a variety of sports, such as volleyball, football, and track and field, include plyometrics to enhance the performances of individuals because studies have shown plyometrics are effective for developing speed and strength capabilities (Chu, 1992). However, few coaches possess adequate knowledge about plyometric exercises; few understand the mechanics of how plyometric training works.

Stretch-Shortening Cycle

The stretch-shortening cycle (SSC) is described as a prestretch of a muscle by an eccentric muscle contraction immediately before a concentric contraction of the same muscle or muscle group (Kreighbaum & Barthels, 1996). The stretching of the muscle prior to the concentric contraction enhances the maximum work output that the muscles can produce (Schenau, Bobbert, & Haan, 1997). The mechanisms responsible for this enhancement are unclear. Authors including Asmussen and Bonde-Petersen (1974) and Komi and Bosco (1978) believed that the extra work is
due to the release of elastic energy stored in the muscle tendon complex during the eccentric contraction. Other authors such as Avis, Schenau, Toussaint, and Huijing (1986) and Schenau et al. (1997) question the role of elastic energy and suggest that nonelastic mechanisms play a role in the enhanced work output of the SCC.

Effects of Prestretch

There is ample evidence that performance (work output) is enhanced by a countermovement (SSC), particularly in quick, discrete movements. Komi and Bosco (1978) demonstrated that subjects achieved a greater jump height in a countermovement jump (CMJ), in which they were allowed to make a downward movement before jumping, than they achieved in a squat jump (SJ), in which they were not allowed to make a countermovement before takeoff. Several factors have been identified as contributors to the increase in work output by a countermovement: the time available for force development, storage and utilization of elastic energy, and the contribution of reflexes (Schenau et al., 1997).

Time Available for Force Development

Performing a countermovement prior to the desired movement allows muscles time to develop force. It takes time for a muscle to reach its maximum force, due in part to the muscle fiber type and to the rate of neuromuscular stimulation by the central nervous system. If the concentric contraction starts as soon as the force begins to rise, part of the shortening distance of the muscle is performed at a submaximal level, thus the total work produced is submaximal (Schenau et al., 1997). This undesirable effect can be avoided by allowing the muscles to build up to a maximum active state before the start of the concentric contraction during a
countermovement. The effect of the time required for force development is supported by Viitasalo and Bosco (1982), who demonstrated that subjects with a relatively large percentage of slow twitch fibers benefit more from a countermovement than subjects with a large percentage of fast-twitch fibers.

Storage and Reutilization of Elastic Energy

A second explanation for the enhancement of maximum work by a countermovement is the storage and reutilization of elastic energy. This explanation is based on the idea that during the countermovement (eccentric phase) active muscles are stretched and able to absorb energy, part of which is temporarily stored in the elastic components of the muscle tendon complex and later reused in the concentric phase, thereby enhancing the maximum work produced (Asmussen & Bonde-Petersen, 1974; Komi & Bosco, 1978). Farley (1997) pointed out that muscles that undergo a SSC produce a power output that exceeds what would be possible without a prestretch. Models of ankle extensor muscle behavior during a jump indicate that substantial energy is stored and released by tendinous structures during a CMJ, contributing 50–70% of the power output at the ankle (Anderson & Pandy, 1993).

However, although there is no question that elastic energy is stored and reused, the assumption that it enhances the maximum work output during the concentric phase is disputed. Although a countermovement stretches the muscles allowing elastic energy to be stored, this elongation occurs at the expense of the length of the contractile elements. Consequently, the contractile elements are not able to do as much work during the concentric phase (Avis et al., 1986). In addition, Chapman and Sanderson (1990) demonstrated that work enhancement due to a
countermovement was not dependent on elastic energy because work output was enhanced in muscle models that did not possess any series elastic components.

**Contribution of Reflexes**

A final possible explanation for the increased work output produced by a countermovement is that the prestretch triggers spinal reflexes that help to increase muscle stimulation during the concentric phase. Sensors within the muscle spindles (proprioceptors) are responsible for “sensing changes in the velocity of the stretch and reflexively producing a quick contraction” (Conatser, 1995, p. 11) of the muscle fibers. The stretch reflex responds to the rate at which a muscle is stretched; the faster a muscle is stretched or lengthened the greater the firing frequency of the proprioceptors and the ensuing reflexive muscle contraction.

**Role of Stretch-Shortening Cycle in Jumping**

**Coupling Phase**

The coupling phase of the SSC is defined as the pause between the eccentric and concentric contractions (Conatser, 1995). During this phase the muscle or muscles involved must switch from overcoming work to acceleration in the opposite direction. There is a significant amount of nerve conduction activity during this phase.

When plyometrics are performed correctly, and the coupling phase is kept short, a powerful response will be created by the agonist muscle groups. A slow coupling phase will cause the energy produced by the eccentric contraction to be given off as heat, and therefore limit the concentric contraction (Conatser, 1995).
Vertical Jump

Vertical jumping is a movement that propels the human body, and thereby the center of gravity (CG), as far as possible in the vertical plane. This is accomplished by creating a high velocity at takeoff that overcomes gravity and propels the body from the ground.

Preparatory Phase

The preparatory phase of the vertical jump is the controlled deceleration of the body that counteracts the effect of gravity, causing an eccentric contraction (stretching) of the muscles of the lower leg, thigh, and trunk. The stretched muscles contribute to the concentric contraction of these muscles at takeoff increasing jump height (Conatser, 1995). This eccentric movement prepares the extensor muscles for the power movement needed for the upward propulsion. The stretched muscles store elastic energy that some authors believe contributes to the contraction force during takeoff.

Takeoff

Takeoff is the coordinated movement of all the flexed joints of the lower extremity to forcefully extend, propelling the body upward (Conatser, 1995). The power needed is derived from the summation of forces from concentric contractions of the hip, knee, and ankle in concert.
Depth Jump

A depth jump is a type of plyometric exercise similar to the vertical jump. However, the subject begins by stepping off the top of a box from varying heights, instead of taking off from the ground. This added height is thought to load the muscles with a greater force stretching the muscles further to increase jump height immediately following the landing.

Jump Height

There is much controversy in the literature about the best height for depth jumping. The height of the box determines the intensity of the exercise and the response of the ensuing muscular contractions. Tippet and Voight (1995) determined that 32 in. was an ideal height for achieving maximum speed in switching from the eccentric phase to the concentric phase. Yessis and Hatfield (1986) stated that the most effective jump height was 30–40 in. Jumping from a height greater than 42 in. was found to be counterproductive because the coupling phase increased and the stored energy was released as heat (Voight & Draovitch, 1991).

Summary

There is a need for more conclusive experimental data on plyometric training and the effect of the SSC on the enhanced concentric phase in order to clarify the storage and reuse of elastic energy as an explanation for the increased work output of an SCC. Right now most of the data on the role of elastic energy are contradictory.
CHAPTER III

METHODS AND PROCEDURES

Plyometric training is becoming quite prevalent in athletics. Plyometrics involve a SSC of the muscles that is believed by some authors to cause the increased work output of the concentric muscle contraction. The purpose of this study was to examine the SSC of muscle contraction during a depth jump (DJ) from various heights, and the traditional standing vertical jump (VJ). Due to the increasing popularity of plyometrics in sports programs, it is important to evaluate both the value and the potential risks involved with plyometric exercises.

In this study, selected EMG and kinematic parameters were compared for the two different jumps. The researcher used surface EMG synchronized with two-dimensional video to analyze the EMG and kinematic response of six muscles in the lower extremity during all phases of the jumps. The following topics will be addressed in this chapter: (a) human subjects approval, (b) subject selection, (c) EMG and filming procedures, (d) data collection, (e) research design, and (f) statistical analysis.

Human Subjects Approval

Approval to conduct this study was required by Western Michigan University’s Human Subjects Institutional Review Board (HSIRB). The appropriate forms were submitted to the HSIRB (Appendix A).
Subject Selection

The 20 subjects participating in this study were female Western Michigan University physical education majors. Volunteers were recruited from various physical education undergraduate classes (Appendix B). The subjects were selected from a pool of 40 volunteers based on their performance of a vertical jump test. The 10 subjects with the highest vertical jump and the 10 subjects with the lowest vertical jump were selected for the study and grouped as skilled and unskilled jumpers, respectively.

Potential subjects answered a health questionnaire (Appendix C) to screen for injuries to the lower extremity sustained in the 6 months prior to the study. Injuries judged serious enough to limit performance or place the individual at an increased risk of injury were grounds for eliminating the individual from participation in the study.

Electromyography Procedures

The EMG responses of the following six muscles or muscle groups were measured during the performance of each depth jump and the vertical jump: (1) biceps femoris (BF), (2) rectus femoris (RF), (3) vastus medialis (VM), (4) semimembranosus/semitendinosus (SS), (5) medial head of the gastrocnemius (MG), and (6) peroneal group (PG). Bipolar surface electrodes, Medi trace, 1 cm, silver/silver chloride (ECE 1801 Graphic Controls, Buffalo, NY) were placed at a point half the distance between the center of the innervation zone (motor point) and the distal tendon of the muscle. The electrodes were placed approximately 1 cm
apart, parallel with the muscle fibers, and at the midline of the muscle. All placement sites were properly prepped before electrode placement.

The EMG electrodes were linked to a Myosystem 2000 EMG data collection system (Noraxon, Phoenix, AZ) integrated with the analog-digital module in a Peak Motion Analysis hardware/software package (Peak Performance Technologies, Inc., Inglewood, CO). The integrated EMG data were filtered using a Butterworth data smoothing procedure. The smoothed EMG data were then transferred to the Myosoft EMG analysis located on a Tenex 486 DX-2 personal computer. The EMG responses for each muscle during the eccentric, coupling, and concentric phases of the muscle contraction were analyzed to determine the point at which peak recruitment takes place.

Filming Procedures

A two-dimensional video analysis of each jump was used to help separate the individual jumps into three phases. A Panasonic AG 450 video camera (Panasonic, Secaucus, NJ) set at 60 HZ was used to record the motion of each jump. Fuji S-VHS ST-120N videotape was used. The video data were synchronized to the EMG data through an event synchronization unit (ESU). The ESU was equipped with a switch to trigger a light-emitting-diode (LED) signal. The signal was simultaneously recorded on the video and the EMG outputs. The data from the film were then matched to the EMG data at a specific point in time.

The EMG data collection was controlled by the ESU. The LED was triggered by the breaking of a light beam that was positioned approximately 18 in. above the ground, parallel to the camera. When the jumping motion was initiated, the light beam was interrupted by the subject’s body and the data collection process was
triggered. EMG data were set to begin recording 1.0 s prior to the LED signal and to end recording 4.0 s following the signal. The EMG data were collected at a rate of 480 Hz, thus producing eight EMG data points for each video frame.

The video camera was set so that the focal length of the lens was perpendicular to the sagittal plane, right side of the jumper. The camera lens was 40 ft from the subject and 1 m above the ground. Subjects performed in front of a contrasting background so that anatomical landmarks could be seen and digitized.

Data Collection Procedures

Data collection took place in the Biomechanics Laboratory in the University Recreation Center, Western Michigan University, Kalamazoo. Subjects were instructed to wear dark-colored shorts above the knee, athletic shoes, low-cut socks, and dark tops for data collection.

Written instructions were read aloud to each subject prior to her participation, and a consent form was read and signed by each participant (Appendix D). The instructions were as follows:

1. You will be given a 5-min warm-up prior to your jumps. Your warm-up will consist of the following: (a) a 3-min ride on a stationary cycle at 50 RPM with a resistance of 1 Kp, (b) specific stretches for the lower extremities, and (c) medium intensity rope jumping for 2 min. All stretches are performed twice for a count of 20 s to 30 s. The stretches include a sitting straight leg toe touch for the hamstrings; a supine, knee to chest stretch, with medial rotation of the lower leg for the gluteals; and a standing, straight leg stretch facing and leaning in toward the wall for the gastrocnemius.
2. During the data collection, you will complete three trials for each of the four different jumping conditions, a total of 12 trials.

3. For the depth jump conditions, you should rebound and reach as high as you can as quickly as possible.

4. For the vertical jump condition, you must jump from both feet simultaneously.

5. In each trial, I will indicate to you when you should jump.

Video Digitizing Analysis

**Jump Heights**

After data collection, the analysis was initiated using the automatic digitizing process. The purpose of the initial digitizing was to establish the vertical height of each trial. To establish the total body CG, 10 anatomical points were digitized. The anatomical points were the distal phalanges, lateral malleolus, knee joint midline, greater trochanter of femur, distal phalanges, midline of the wrist, elbow joint midline, greater tuberosity of humerus, sternum, tragus of ear, top of head, and crotch. The right side of the body was digitized.

Each subject was first digitized in a standing position to establish the height of the standing CG. Then the trials for each subject were digitized to determine the maximum vertical displacement of the CG. The vertical coordinate for standing height CG was subtracted from the vertical coordinate representing maximal vertical displacement of the CG to calculate jump height. The highest jump of the three trials for each condition was selected for further analysis.
Video Analysis

The highest jump of each condition was then digitized for analysis purposes. The analysis began three frames prior to the LED signal and ended three frames after peak height of CG. This ensured that all EMG and kinematic data would be analyzed. At this time the trial was saved on the computer for further analysis.

For a second analysis only five anatomical landmarks were digitized: (1) distal phalanges, (2) lateral malleolus, (3) knee joint midlines, (4) greater trochanter of femur, and (5) sternum. All anatomical landmarks were digitized from the right side of the body. Four significant movement events were marked as they were seen by the investigator from the video: (1) ground contact, (2) cessation of downward motion, (3) beginning of upward motion, and (4) takeoff. After all the jumps were digitized, data were smoothed using a Butterworth filter (6 Hz).

Calculated Angles

In the study three joints were analyzed: (1) the ankle, (2) the knee, and (3) the hip. Each joint angle was defined by two adjacent segments and the articulating joint. A hypothetical line was drawn from the distal end of each segment to the articulating joint for each joint. For the ankle joint, a line was drawn from the right metatarsal to the ankle joint, and a second line was drawn from the knee to the ankle joint. The ankle angle was measured on the anterior side of these two intersecting segments.

For the knee joint, a line was drawn from the center of the ankle joint to the knee joint midline, and a second line was drawn from the greater trochanter of the femur to the knee joint midline. The knee angle was measured on the posterior side of these two intersecting segments.
For the hip joint, a line was drawn from the midline of the knee to the greater trochanter of the femur, and a second line was drawn from the sternum to the greater trochanter of the femur. The hip angle was measured on the anterior side of these two intersecting segments.

**Event Frame Verification**

Stick figures were matched to coincide with the angles of the ankle, knee, and hip throughout the entire digitized motion because the exact event frames for cessation of downward motion and beginning of upward motion were difficult to identify during the digitizing process. The researcher was able to manually control the computer to move one frame at a time until a previously selected event frame was reached. This frame was matched to joint angle displacement data. If needed, event frames were adjusted according to the following criteria:

1. Cessation of downward motion was based on the angular displacement data. A frame was selected that represented the end of downward motion using a value of ±2 across three consecutive frames as the standard.

2. Beginning upward motion was based on the angular displacement data. A frame was selected that represented an increase in the joint angles (ankle, knee, and hip) of a minimum of ±2 across the remaining frames.

**Phases of Motion**

**Depth Jumps**

Phases of motion for the depth jumps were defined by the following event verification frames:
1. Eccentric phase began when one or both feet made contact with the ground and ended when the body’s CG reached the lowest vertical displacement, and when ankle, knee, and hip joints reached maximum flexion.

2. Concentric phase began when the body’s CG began its upward motion and ended at takeoff.

3. Coupling phase was the time between the eccentric phase and the concentric phase.

**Vertical Jumps**

The eccentric phase was not analyzed in the vertical jump since there was not a method to determine the starting point of the eccentric phase similar to the starting point determined for the depth jumps. The concentric phase and coupling phase were defined the same as they were for the depth jump.

**EMG Analysis**

All EMG data were transferred to the Myosoft system for analysis. The integrated EMG wave form was marked at the greatest peak recruitment that occurred after ground contact, prior to takeoff. From this marker time to peak recruitment was calculated. The time was positive if peak recruitment occurred after ground contact and negative if it occurred before ground contact.

**Data Analysis**

**Independent Variables**

The independent variables for this study were as follows:
1. Four levels of jumps: vertical jump (VJ), and depth jumps performed at 1-ft (DJ 1), 2-ft (DJ 2), and 3-ft (DJ 3).

2. The six muscles and muscle groups: biceps femoris, vastus medialis, rectus femoris, semitendinosus/semimembranosus, gastrocnemius, and peroneal group.

3. Two groups, skilled and unskilled, based on vertical jump performance.

A split-plot factorial analysis of variance (ANOVA) was used to analyze the independent variables.

**Dependent Variables**

ANOVA's were calculated on the following dependent variables:

1. Four coupling times were calculated. Coupling times began with cessation of (a) vertical displacement of CG, (b) hip ROM, (c) knee ROM, and (d) ankle ROM. The coupling phase ended when CG began vertical displacement and the hip, knee, and ankle began extending. Coupling time, defined by the cessation of CG, was used to analyze EMG data for all six muscles. Coupling time, defined by cessation of the joint movements, was used for only the muscles that crossed that joint.

2. Peak EMG was defined by the maximum contraction measured in microvolts of (a) rectus femoris, (b) vastus medialis, (c) medial head of the gastrocnemius, (d) peroneal group, (e) bicep femoris, and (f) semimembranosus/ semitendinosus.

3. Relative time to peak EMG was calculated by dividing the time that peak EMG occurred by the total time of the eccentric, coupling, and concentric phases.
CHAPTER IV
RESULTS AND DISCUSSION

Introduction

This chapter contains the results obtained in the previously described study. The purpose of the study was to compare and describe both the kinematic and electromyographic differences during the eccentric, coupling, and concentric phases of a depth jump and a standing vertical jump. In addition, the study was used to attempt to verify a coupling phase in the jumping movement. The following topics will be addressed in this chapter: (a) the kinematic similarities and differences for each phase, (b) the phase in which peak EMG occurs for each of the six leg muscles monitored, and (c) the peak EMG among the different jumping conditions for each of the six muscles.

The data were analyzed at Western Michigan University, Kalamazoo. A split-plot factorial ANOVA was calculated for each of the dependent variables. A simple or simple simple main effects test was used for multiple comparisons when a first- or second-order interaction effect was significant.

Results

Characteristics of Subjects

The subjects consisted of 20 female Western Michigan University physical education majors. The subjects were not involved in intercollegiate athletics. The
subjects were selected and grouped as skilled or unskilled jumpers based on their performance on a vertical jump test.

Temporal Data

Eccentric Phase

The eccentric phase began when one or both feet made contact with the ground and ended with the cessation of vertical displacement of the body’s CG, and when the hip, knee, and ankle joints reached maximum flexion. The three depth jumps and four methods of cessation of vertical displacement were analyzed for the two groups. The VJ was not analyzed since there was not a method to determine the starting point of the eccentric phase similar to the starting point determined for the depth jumps. An ANOVA summary is presented in Table 1. The following results were found:

1. A significant difference was found between the skilled and unskilled jumpers, $F(1, 18) = 8.75$, $p = .01$. The mean times for the skilled and unskilled jumpers were 258.26 ms and 200.60 ms, respectively.

2. No significant difference was found among the three depth jumps, $F(2, 36) = 2.85$, $p = .07$. The means for DJ 1, DJ 2, and DJ 3 were 213.35 ms, 226.53 ms, and 248.41 ms, respectively.

3. No significant difference was found among the methods for determining the end of the eccentric phase, $F(3, 54) = 2.14$, $p = .11$. The means for the CG, hip, knee, and ankle methods were 223.27 ms, 226.38 ms, 238.57 ms, and 229.50 ms, respectively.
Table 1
Analysis of Variance for Temporal Data for the Eccentric Phase

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<td>199469.00</td>
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<td>Jumps (J)</td>
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<td>2</td>
<td>25093.63</td>
<td>2.85</td>
<td>0.07</td>
</tr>
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<td>2</td>
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<td>0.43</td>
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<td>8818.11</td>
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</tr>
<tr>
<td>Methods (M)</td>
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<td>2615.05</td>
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<td>0.11</td>
</tr>
<tr>
<td>M × G</td>
<td>2026.61</td>
<td>3</td>
<td>675.54</td>
<td>0.55</td>
<td>0.65</td>
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<tr>
<td>M × subj. w. groups</td>
<td>65966.66</td>
<td>54</td>
<td>1221.60</td>
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</tr>
<tr>
<td>J × M</td>
<td>2757.54</td>
<td>6</td>
<td>459.59</td>
<td>0.67</td>
<td>0.67</td>
</tr>
<tr>
<td>G × J × M</td>
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<td>6</td>
<td>1005.48</td>
<td>1.47</td>
<td>0.20</td>
</tr>
<tr>
<td>JM × subj. w. groups</td>
<td>74104.42</td>
<td>108</td>
<td>686.15</td>
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</tr>
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</table>

4. No significant differences were found for the first- or second-order interaction effects.

**Coupling Phase**

The coupling phase began with the cessation of movement of the CG, hip, knee, and ankle and ended when movement began for the concentric phase. The VJ
and three depth jumps and four methods were analyzed for the two groups. An ANOVA summary is presented in Table 2. The following results were found:

1. No significant difference was found between the skilled and unskilled jumpers, $F(1, 18) = 2.28, p = .15$. The mean times for the skilled and unskilled jumpers were 18.49 ms and 19.23 ms, respectively.

2. No significant difference was found among the VJ and three depth jumps, $F(3, 54) = .03, p = .99$. The means for the VJ, DJ 1, DJ 2, and DJ 3 were 18.91 ms, 18.70 ms, 18.91 ms, and 18.91 ms, respectively.

3. A significant difference was found among the methods used for determining the beginning and ending of the coupling phase, $F(3, 54) = 44.84, p = .00$. The means for the CG, hip, knee, and ankle were 24.23 ms, 17.00 ms, 17.21 ms, and 17.00 ms, respectively.

4. No significant interaction effects were found for the jumps by group, jumps by methods, or group by jumps by methods.

5. A significant interaction effect was found for the methods by group, $F(3, 54) = 2.78, p = .05$.

A simple main effects test was calculated to determine where differences occurred among the groups for each method. The simple main effects summary is presented in Table 2. The simple main effects test found a significant difference for groups at Method 1 (CG), $F(1, 72) = 2.63, p < .05$. The means for the CG method for the skilled and unskilled jumpers were 22.53 ms and 25.93 ms, respectively. There was also a significant difference for methods for Groups 1 and 2, $F(3, 54) = 3.19, p < .05$ and $F(3, 54) = 66.38, p < .05$, respectively. The means for the CG, hip, knee, and ankle methods for the skilled jumpers were 22.53 ms, 17.00 ms, 17.43 ms, and 17.00 ms, respectively. The means for the CG, hip, knee, and ankle methods for
Table 2
Analysis of Variance and Simple Main Effects for Temporal Data for the Coupling Phase

<table>
<thead>
<tr>
<th>Source</th>
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<th>MS</th>
<th>F</th>
<th>p</th>
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<td>44.25</td>
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<td>Subj. w. groups</td>
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<td>18</td>
<td>19.37</td>
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<tr>
<td><strong>Within Subjects</strong></td>
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<td></td>
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<tr>
<td>Jumps (J)</td>
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<td>3</td>
<td>0.90</td>
<td>0.03</td>
<td>0.99</td>
</tr>
<tr>
<td>J × G</td>
<td>9.93</td>
<td>3</td>
<td>3.31</td>
<td>0.12</td>
<td>0.95</td>
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<tr>
<td>J × Subj. w. groups</td>
<td>1450.42</td>
<td>54</td>
<td>26.86</td>
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<td>Methods (M)</td>
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<td>3</td>
<td>1024.44</td>
<td>44.84*</td>
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</tr>
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<td>M × G</td>
<td>90.56</td>
<td>3</td>
<td>63.52</td>
<td>2.78*</td>
<td>0.05</td>
</tr>
<tr>
<td>GR at M₁</td>
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<td>1</td>
<td>57.80</td>
<td>2.63*</td>
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<tr>
<td>GR at M₂</td>
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<td>1</td>
<td>0.00</td>
<td>0.00</td>
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<tr>
<td>GR at M₃</td>
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<td>1</td>
<td>0.90</td>
<td>0.04</td>
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</tr>
<tr>
<td>GR at M₄</td>
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<td>1</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>Within Cell</td>
<td>1582.28</td>
<td>72</td>
<td>21.98</td>
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<tr>
<td>M at GR₁</td>
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<td>3</td>
<td>72.85</td>
<td>3.19*</td>
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<td>M at GR₂</td>
<td>597.42</td>
<td>3</td>
<td>199.14</td>
<td>66.38*</td>
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<tr>
<td>M × Subj. w. groups</td>
<td>1233.67</td>
<td>54</td>
<td>22.85</td>
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<tr>
<td>J × M</td>
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<td>2.51</td>
<td>0.09</td>
<td>0.99</td>
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<tr>
<td>G × J × M</td>
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<td>3.31</td>
<td>0.12</td>
<td>0.99</td>
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<td>JM × Subj. w. groups</td>
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<td>162</td>
<td>26.77</td>
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the unskilled group were 25.93 ms, 17.00 ms, 17.00 ms, and 17.00 ms, respectively. The Tukey HSD multiple comparison test was calculated to determine where multiple comparisons were significant. There were significant differences for both groups between methods (a) CG and hip, (b) CG and knee, and (c) CG and ankle.

Concentric Phase

The concentric phase began with the upward motion as identified by the upward vertical displacement of the CG and the beginning of extension of the hip, knee, and ankle joints. The phase ended at takeoff. The VJ and three depth jumps and four methods were analyzed for the two groups. The ANOVA summary is presented in Table 3. The following results were found:

1. A significant difference was found between the skilled and unskilled jumpers, $F(1, 18) = 6.53, p = .02$. The mean times for the skilled and unskilled jumpers were 279.86 ms and 238.32 ms, respectively.

2. A significant difference was found among the VJ and three depth jumps, $F(3, 54) = 8.39, p = .00$. The means for the VJ and DJ 1, DJ 2, and DJ 3 were 288.58 ms, 226.10 ms, 247.56 ms, and 274.13 ms, respectively.

3. A significant difference was found among the methods for determining the beginning of the concentric phase, $F(3, 54) = 4.78, p = .01$. The means for the CG, hip, knee, and ankle were 257.34 ms, 270.30 ms, 245.86 ms, and 262.86 ms, respectively.

4. No significant interaction effects were found for the jumps by group or methods by group.
Table 3

Analysis of Variance and Simple Simple Main Effects for Temporal Data for the Concentric Phase

<table>
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<th>Source</th>
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<td>Within Subjects</td>
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<td>Jumps (J)</td>
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<td>0.00</td>
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<td>J × G</td>
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<td>0.84</td>
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<td>J × Subj. w. groups</td>
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<td>Methods (M)</td>
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<td>M × G</td>
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<tr>
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<td>J × M</td>
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<tr>
<td>G × J × M</td>
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<td>1799.93</td>
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Table 3—Continued

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<td>50059.02</td>
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</table>

5. A significant interaction effect was found for jumps by methods and group by jumps by methods, $F(9, 162) = 2.84$, $p = .00$, and $F(9, 162) = 2.02$, $p = .04$, respectively.

A post-hoc simple simple main effects test was calculated to determine where differences occurred among the jumps and methods for each group. The simple simple main effects summary is presented in Table 3. The following results were found:

1. A significant difference was found for groups at the VJ, Method 3 (knee), $F(1, 180) = 5.08$, $p < .05$. The mean times for the skilled and unskilled jumpers were 285.60 ms and 231.20 ms, respectively.

2. A significant difference was found for groups at DJ 1, Method 1 (CG), $F(1, 180) = 5.73$, $p < .05$. The mean times for the skilled and unskilled jumpers were 258.40 ms and 200.60 ms, respectively.

3. A significant difference was found for groups at DJ 1, Method 2 (hip), $F(1, 180) = 6.79$, $p < .05$. The mean times for the skilled and unskilled jumpers were 268.60 ms and 205.70 ms, respectively.
4. A significant difference was found for groups at DJ 1, Method 3 (knee), $F(1, 180) = 3.89, p < .05$. The mean times for the skilled and unskilled jumpers were 238.00 ms and 190.40 ms, respectively.

5. A significant difference was found for groups at DJ 3, Method 2 (hip), $F(1, 180) = 7.54, p < .05$. The mean times for the skilled and unskilled jumpers were 311.10 ms and 244.80 ms, respectively.

6. A significant difference was found for groups at DJ 3, Method 4 (ankle), $F(1, 180) = 6.43, p < .05$. The mean times for the skilled and unskilled jumpers were 307.70 ms and 246.50 ms, respectively.

7. A significant difference was found for methods at GR 1 (skilled), $F(3, 72) = 5.46, p < .05$. The means for the CG, hip, knee, and ankle for the skilled group were 279.23 ms, 294.95 ms, 266.05 ms, and 279.23 ms, respectively.

8. A significant difference was found for methods at GR 2 (unskilled), $F(3, 72) = 7.57, p < .05$. The means for the CG, hip, knee, and ankle methods for the unskilled group were 235.45 ms, 245.65 ms, 225.68 ms, and 246.50 ms, respectively. The Tukey HSD test indicated a significant difference between the knee and hip methods for the skilled group. For the unskilled group significant differences were found between methods (a) knee and hip, and (b) knee and ankle.

**EMG Data**

**Phases**

The phase in which peak EMG activity occurred for each muscle was calculated. The results are presented in Table 4. For the VJ, all of the muscles except the peroneal group reached peak EMG in the concentric phase for both groups. The
Table 4
Relative Time for the Eccentric Phase for Time to Peak EMG

<table>
<thead>
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<th></th>
<th>VJ</th>
<th>D1</th>
<th>D2</th>
<th>D3</th>
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<td>% time in Ecc</td>
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<tr>
<td>Skilled</td>
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<td>.453</td>
<td>.472</td>
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<td>RF</td>
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<td>.646</td>
<td>.483</td>
<td>.428</td>
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<td>VM</td>
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<td>.705</td>
<td>.345</td>
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<td>% time in Ecc</td>
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<td>.436</td>
<td>.443</td>
<td>.409</td>
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<td>RF</td>
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<td>.622</td>
<td>.518</td>
<td>.272</td>
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<td>.237</td>
<td>.380</td>
<td>.308</td>
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<td>.399</td>
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<td>.279</td>
<td>.308</td>
<td>.129</td>
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<tr>
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<td>.453</td>
<td>.552</td>
<td>.173</td>
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<td>SM</td>
<td>.792</td>
<td>.518</td>
<td>.502</td>
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peroneal group reached peak EMG during the eccentric phase for the skilled group. For DJ 1, all six muscles reached peak EMG in the concentric phase for the skilled group. For the unskilled group the RF, BF, and SS reached peak EMG in the concentric phase, while the VM, MG, and PG reached peak EMG in the eccentric phase. For DJ 2, all of the muscles except the PG reached peak EMG in the
concentric phase for the skilled group. For the unskilled group, the results were the same as DJ 1. Finally, for DJ 3, all six muscles reached peak EMG during the eccentric phase for both groups.

**ANOVAs**

A split-plot factorial ANOVA was calculated to determine if peak EMG recruitment was different across the jump conditions. The ANOVA consisted of two factors: (1) four jump conditions, VJ and DJs from 1, 2, and 3-ft; and (2) two jump groups, skilled and unskilled. An ANOVA was calculated for each of the six leg muscles monitored.

**Rectus Femoris**

The ANOVA summary for peak EMG for the rectus femoris is presented in Table 5. The following results were found:

1. No significant difference was found between the skilled and unskilled jumpers, $F(1, 18) = .06, p = .81$. The means for the skilled and unskilled jumpers were 719.38 mv and 692.89 mv, respectively.

2. No significant difference was found among the VJ and three depth jumps, $F(3, 54) = 2.32, p = .09$. The means for the VJ, DJ 1, DJ 2, and DJ 3 were 661.86 mv, 542.20 mv, 716.10 mv, and 904.37 mv, respectively.

3. No significant interaction effect was found for group by jumps, $F(3, 54) = .74, p = .54$. 
Table 5
Analysis of Variance for Peak EMG for the Rectus Femoris

<table>
<thead>
<tr>
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<td>Group</td>
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<tr>
<td>Jumps</td>
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<td>454849.71</td>
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<tr>
<td>G x J</td>
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<td>195695.30</td>
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</table>

Vastus Medialis

The ANOVA summary for peak EMG for the vastus medialis is presented in Table 6. The following results were found:

1. A significant difference was found between the skilled and unskilled jumpers, $F(1, 18) = 10.28, p = .01$. The means for the skilled and unskilled jumpers were 1226.35 mv and 695.08 mv, respectively.

2. No significant difference was found among the VJ and three depth jumps, $F(3, 54) = .39, p = .76$. The means for the VJ, DJ 1, DJ 2, DJ 3 were 887.70 mv, 943.74 mv, 1011.54 mv, and 999.89 mv, respectively.

3. No significant interaction effect was found for group by jumps, $F(3, 54) = .25, p = .86$. 
Table 6
Analysis of Variance for Peak EMG for the Vastus Medialis

<table>
<thead>
<tr>
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<tr>
<td>Group</td>
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<td>5644872.80</td>
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<td>Subj w/in groups</td>
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<td>Within Subj</td>
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<td></td>
<td></td>
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<tr>
<td>Jumps</td>
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<td>64920.20</td>
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<td>J x Subj w/in groups</td>
<td>9080513.30</td>
<td>54</td>
<td>168157.65</td>
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<td></td>
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</tbody>
</table>

Gastrocnemius

The ANOVA summary for peak EMG for the gastrocnemius is presented in Table 7. The following results were found:

1. No significant difference was found between the skilled and unskilled jumpers, $F(1, 18) = 1.86, p = .19$. The means for the skilled and unskilled jumpers were 853.53 mv and 585.38 mv, respectively.

2. No significant difference was found among the VJ and three depth jumps, $F(3, 54) = 1.73, p = .17$. The means for the VJ, DJ 1, DJ 2, and DJ 3 were 727.05 mv, 531.70 mv, 760.78 mv, and 858.29 mv, respectively.

3. No significant interaction effect was found for group by jumps, $F(3, 54) = 1.01, p = .39$. 
Table 7
Analysis of Variance for Peak EMG for the Gastrocnemius

<table>
<thead>
<tr>
<th>Source</th>
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<td>Group</td>
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<td>1438148.20</td>
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<td>Subj w/in groups</td>
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<td></td>
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<tr>
<td>Jumps</td>
<td>1125885.70</td>
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<td>G x J</td>
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<td>11749192.00</td>
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<td>217577.62</td>
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</table>

**Peroneal Group**

The ANOVA summary for the peak EMG of the peroneal group is presented in Table 8. The following results were found:

1. No significant difference was found between skilled and unskilled jumpers, $F(1, 17) = 2.87, p = .11$. The means for the skilled and unskilled jumpers were 534.68 mv and 433.14 mv, respectively.

2. No significant difference was found among the VJ and three depth jumps, $F(3, 51) = 1.45, p = .24$. The means for the VJ, DJ 1, DJ 2, and DJ 3 were 430.20 mv, 413.00 mv, 503.53 mv, and 578.21 mv, respectively.

3. No significant interaction effect was found for group by jumps, $F(3, 51) = .07, p = .98$. 
The ANOVA summary for peak EMG for the bicep femoris is presented in Table 9. The following results were found:

1. No significant difference was found between skilled and unskilled jumpers, $F(1,18) = .10, p = .76$. The means for the skilled and unskilled jumpers were 519.92 mv and 584.62 mv, respectively.

2. No significant difference was found among the VJ and three depth jumps, $F(3, 54) = 1.04, p = .38$. The means for the VJ, DJ 1, DJ 2, and DJ 3 were 454.10 mv, 536.93 mv, 449.13 mv, and 768.91 mv, respectively.

3. No significant interaction effect was found for group by jumps, $F(3, 54) = .66, p = .58$. 

### Table 8

**Analysis of Variance for Peak EMG for the Peroneal Group**

<table>
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<tr>
<th>Source</th>
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<tr>
<td>Jumps</td>
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<tr>
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</table>

**Biceps Femoris**

The ANOVA summary for peak EMG for the bicep femoris is presented in Table 9. The following results were found:

1. No significant difference was found between skilled and unskilled jumpers, $F(1,18) = .10, p = .76$. The means for the skilled and unskilled jumpers were 519.92 mv and 584.62 mv, respectively.

2. No significant difference was found among the VJ and three depth jumps, $F(3, 54) = 1.04, p = .38$. The means for the VJ, DJ 1, DJ 2, and DJ 3 were 454.10 mv, 536.93 mv, 449.13 mv, and 768.91 mv, respectively.

3. No significant interaction effect was found for group by jumps, $F(3, 54) = .66, p = .58$. 

Table 9
Analysis of Variance for Peak EMG for the Biceps Femoris

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<tr>
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<tr>
<td>Jumps</td>
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Semitendinosus/Semimembranosus

The ANOVA summary for peak EMG for the semitendinosus/semimembranosus is presented in Table 10. The following results were found:

1. No significant difference was found between the skilled and unskilled jumpers, $F(1, 18) = 1.28$, $p = .27$. The means for the skilled and unskilled jumpers were 656.75 mv and 403.12 mv, respectively.

2. No significant difference was found among the VJ and three depth jumps, $F(3, 54) = .63$, $p = .60$. The means for the VJ, DJ 1, DJ 2, and DJ 3 were 478.27 mv, 619.18 mv, 445.09 mv, and 577.18 mv, respectively.

3. No significant interaction effect was found for group by jumps, $F(3, 54) = .24$, $p = .87$. 
Table 10

Analysis of Variance for Peak EMF for the Semitendinosus/Membranosus

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<tr>
<td>Jumps</td>
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</tr>
<tr>
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</table>

Discussion

**Temporal Data**

According to Yessis and Hatfield (1986), the key to obtaining a maximal explosive take-off in jumping was to produce maximal muscular contraction in the shortest amount of time. This is achieved by a forceful eccentric contraction followed immediately by an ensuing concentric contraction of the hip, knee, and ankle extensors. The DJ was designed to accomplish this by utilizing body weight, momentum, and gravitational forces. The result would then be a powerful eccentric contraction that allows a maximal stretch reflex and storage of elastic energy.

The results of this study indicated significant differences in eccentric and concentric phase times between the skilled and unskilled groups. The skilled group
spent more time in the eccentric and concentric phases. The more time spent in the eccentric phase allowed for maximal force development for the ensuing concentric phase. The skilled jumpers created a greater impulse by spending more time in order to create a greater force. The subjects in the unskilled group did not spend enough time in the eccentric phase to produce maximal force.

Schenau et al. (1997) suggested that a greater eccentric phase allows for a greater stretch to enhance the work output produced in the concentric phase. The skilled jumpers spent more time in the eccentric phase, maximizing the stretch and absorption of elastic energy. The results of this investigation relating to coupling phase time are not consistent with findings of previous investigations. A number of previous studies indicated that jump performance is dependent on the time spent in the coupling phase (Chu, 1992; Conatser, 1995; Komi & Bosco, 1978; Yessis & Hatfield, 1986). The previous studies suggested that if the coupling phase was kept short during a depth jump, a powerful response would be created by the agonist muscles due to the storage and utilization of elastic energy. If the coupling phase was too long, the stored elastic energy would be dissipated as heat, thereby limiting the concentric contraction. However, the results of this study indicated no significant difference in the time spent in the coupling phase between the skilled and unskilled jumpers. Since the researcher for this study could not find any data that listed optimal times for the coupling phase, the times found in this study for all of the subjects could have been less than the highest times. This would suggest that both groups achieved an optimal coupling phase, but the skilled group reached maximal force production by spending more time in the eccentric phase, allowing time for maximal force development and the maximal storage of elastic energy.
Peak EMG Data

No significant differences in peak EMG were found among the jump conditions for the six muscles or muscle groups studied in this investigation. There was a significant difference between groups for the vastus medialis. Since this muscle provides medial stability for the knee in addition to controlling knee flexion, it may have played an important role in maintaining balance for the unskilled group.

The results of the muscle firing sequence found in this study were not consistent with other results presented by Conatser (1995). They indicated that a rank firing order existed from proximal to distal (hip, knee, ankle). In this study the PG and MG muscles were consistently high in the firing order.

For the VJ, DJ 1, and DJ 2, the skilled jumpers reached peak EMG activity in the concentric phase for five of the six muscles for maximal force output. The unskilled had more muscles peaking in the eccentric phase in DJ 1 and DJ 2, thereby diminishing the force output in the concentric phase. All six muscles reached peak EMG activity in the eccentric phase for both groups during DJ 3. A depth jump of 3 ft may have been too high for successful performance. This supports findings by Tippet and Voight (1995) that suggest 32 in. as the ideal height for performing depth jumps.
CHAPTER V

SUMMARY, FINDINGS, CONCLUSIONS, AND RECOMMENDATIONS

Summary

Plyometric training is a technique that enhances neuromuscular excitability, that may in turn increase the ability to store and utilize elastic energy in order to achieve a greater work output. The purpose of this study was to determine if there were temporal and EMG differences between two different jumping techniques, the vertical jump and depth jumps of varying heights.

Twenty Western Michigan University female physical education majors performed both the vertical jump and depth jumps from 1 ft, 2 ft, and 3 ft. Each subject performed three trials for each of the four jumping conditions. Temporal and EMG data were collected concerning: (a) the duration of time spent in each phase of the jumps, (b) the kinematic similarities and differences for each phase, (c) peak EMG activity between groups for the six leg muscles monitored, and (d) the peak EMG among the different jumping conditions for each of the six muscles or muscle groups. A split-plot factorial ANOVA was calculated for each of the dependent variables. A simple or simple simple main effects test was used for multiple comparisons when a first- or second-order interaction effect was significant.

Findings

Relevant findings for the study included the following:
1. A significant difference was found between the skilled and unskilled groups in the eccentric and concentric phases. There was no significant difference between the groups in the coupling phase.

2. A significant difference was found among the jump conditions in the concentric phase, while there was no significant differences among jumps in the eccentric and coupling phases.

3. There were significant differences among the methods for determining the coupling phase and concentric phase. There was no significant difference among the methods for determining the eccentric phase.

4. A significant difference was found in the peak EMG of the VM between the skilled and unskilled groups.

5. No significant differences were found among jumping conditions for the six muscles monitored.

Conclusions

The findings in this study indicated the following conclusions:

1. Skilled jumpers spent more time in the eccentric and concentric phases than the unskilled jumpers; however, both groups spent approximately equal time in the coupling phase.

2. There were no differences in eccentric or coupling phase times for the three depth jumps; however, there were differences in the concentric phase.

3. The time spent in the coupling phase measured by the cessation of motion of the CG, hips, knees, and ankles was not the same for the skilled and unskilled groups. This same phenomenon was found for the concentric phase, but no differences existed for the eccentric phase.
4. For the six muscles monitored, the peak EMG was similar for DJ 3, DJ 2, DJ 1, and the VJ. The peak EMG was also similar between skilled and unskilled, except for the VM.

Recommendations

The following recommendations for future research in this area need to be considered:

1. A larger sample size would increase the external validity.

2. Research could be conducted using athletes who train specifically for participation in sports that involve jumping.

3. A film speed higher than 60 frames per second could be more beneficial due to the speed of jumping.

4. Additional muscles involved in the jumping motion could be monitored.
Appendix A

Human Subjects Institutional Review Board
Letter of Approval
Date: 3 February 1998

To: Roger Zabik, Principal Investigator
   Mary Dawson, Co-Principal Investigator
   Nick Juday, Student Investigator
   Amanda Albright, Student Investigator

From: Richard Wright, Chair

Re: Extension and Changes to HSIRB Project Number 96-02-01

This letter will serve as confirmation that the extension and changes to your research project "An Investigation of the Temporal Relationships Between the Phases of Movement and the EMG Response of Selected Muscles Involved in Both the Vertical and Depth Jumps" requested in your memo dated 19 November 1997 have been approved by the Human Subjects Institutional Review Board.

The conditions and the duration of this approval are specified in the Policies of Western Michigan University.

Please note that you may only conduct this research exactly in the form it was approved. You must seek specific board approval for any changes in this project. You must also seek reapproval if the project extends beyond the termination date noted below. In addition if there are any unanticipated adverse reactions or unanticipated events associated with the conduct of this research, you should immediately suspend the project and contact the Chair of the HSIRB for consultation.

The Board wishes you success in the pursuit of your research goals.

Approval Termination: 3 February 1999
Appendix B

Recruitment Script
Professors Mary Dawson and Roger Zabik, and graduate student Amanda Albright are looking for volunteers to participate in a research project. Volunteers must be female undergraduate physical education majors. The purpose of the study is to compare temporal data during the phase of a vertical jump where elastic loading of the bones, muscles, tendons, and ligaments occurs. Four jumps will be studied; three depth jumps from heights of 1.0 ft, 2.0 ft, and 3.0 ft, and a vertical jump from ground level. If you volunteer, we will measure your vertical jump performance and place you in subject pool. We will need only approximately 20 minutes of your time to complete this initial assessment. Only 20 individuals will be selected from the subject pool for participation, you will be scheduled for a second session that will last approximately 35 minutes. During this session you will first warm up and then perform three trials for each of the four jumps. You will be video taped and your muscular response will be monitored using surface electrodes. These electrodes adhere to the skin with an adhesive. To prepare the skin for electrode placement, shaving may be required. The trials will occur consecutively but the order that you will perform the jumps will be determined at random. All testing will take place in the University Recreation Center in the vicinity of the HPER laboratory complex.

If you volunteer, you will be asked to fill out a subject screening form. The purpose of the form is to evaluate whether there is a physical reason why you should not participate in this study. Should you answer "yes" to any of the questions you will be excluded from the study. If you volunteer, you must read and sign an informed consent before participating. You have the option of voluntarily terminating your participation, your decision not to participate will have no effect academically in any way. All test information will be kept confidential. Upon your request, the results of the study will be shared with you. If you are interested in volunteering, please sign your name below along with your telephone number. Thank you!

Name                      Number                      Name                      Number
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
Appendix C

Health Questionnaire
SUBJECT SCREENING FORM

Code Number __________________

Please answer 'yes' or 'no' to the following questions:

____ 1. Have you suffered a leg injury (strain, sprain, torn cartilage, ligament tear, fracture) in the last 6 months?

____ 2. Have you suffered a hip or groin injury (strain, sprain, fracture) in the last 6 months?

____ 3. Have you suffered a back injury (strain, sprain, fracture, disc rupture, pinched nerve) in the last 6 months?

____ 4. Do you have any chronic condition (back problems, bad knees, bad hips, weak ankles) that might be aggravated by exercise?

____ 5. Do you have arthritis?

____ 6. Are you pregnant?

____ 7. Do you have osteoporosis?

Failure to answer any of these questions will result in elimination from the study. If a potential subject answers ‘yes’ to any of these questions, she does not qualify for participation in this study.
Appendix D

Informed Consent
Western Michigan University  
Department of Health, Physical Education, and Recreation

Principle Co-Investigators: Drs. Roger M. Zabik and Mary L. Dawson  
Research Associate: Amanda Albright

I understand that I have been invited to participate in a research project entitled "An Investigation of the Temporal Relationships Between the Phases of Movement and the EMG Response of Selected Muscles Involved in Both the Vertical and Depth Jumps". The purpose of this study is to attempt to verify an amortization phase in the jumping movement and determine the degree to which the selected muscles are recruited during the jumps. The amortization phase occurs while you are in contact with the ground. It is the time between the end of downward motion and the start of the upward motion. I understand that this project is Amanda Albright's thesis project.

I understand that there are no direct benefits from participating in this study. However, I understand that the knowledge gained will help clinicians and coaches make more informed decisions concerning the use of the plyometric exercise technique.

I understand that as a volunteer, I will complete a Subject Screening Form (questionnaire). The results of this form may exclude me from participating in this study.

I understand that as a volunteer, I will initially perform a vertical jump (3 trials). This initial test will take approximately 20 minutes. If I am selected as a subject, I will perform both a vertical jump and three depth jumps. The depth jumps will occur from three heights: 1.0 ft, 2.0 ft, and 3.0 ft. The order that I will perform these jumps will be randomly determined. I will perform 3 consecutive trials for each of the jumps. This second testing session will take approximately 35 minutes. During the second testing, I understand that each jump will be randomly recorded and the muscle responses for six major muscles in the leg and thigh will be recorded. The muscle response for the six muscles will be monitored by electrodes placed on the skin over the muscles and attached with an adhesive backing. I also understand that I will participate in a warm-up prior to the initial vertical jump test session and the second data collection session if I am selected as a subject.

I also understand that there will be no expected risks associated with my participation in this study. However, ankle sprains or strains, lower back strains, or bone fractures are possible during the jumping movements. In the event that an accidental injury occurs, appropriate emergency measures will be taken; however, no treatment or compensation will be provided beyond that provided in this consent form.

I realize that my participation will be completely confidential, and that only a number will be used to identify me as a participant. Any list of names will be destroyed upon completion of the study. The video tape made during the study and all other analytical data will be kept in a locked file cabinet in the HPER laboratory complex for three years. Only the co-investigators have a key. I understand that I may refuse to participate at any time during the study. This refusal will in no way jeopardize my standing at Western Michigan University.

If I have questions or concerns about this study, I may contact Dr. Roger Zabik at (616) 387-2720 or Dr. Mary Dawson at (616) 387-2720 in the Health, Physical Education, and Recreation Department or Amanda Albright at (616) 323-2622. I may also contact the Chair of the Human Subjects Institutional Review Board at 387-8293 or the Vice President for Research at 387-8298 with any concern I may have.

I am covered by my own medical insurance, or otherwise accept full responsibility for any and all medical expenses I may incur as a result of my participation in this study.
My signature below indicates that I understand the purpose and requirements of my participation in the study.

Signature  Date


